Original article

Bariatric surgery is expensive but improves co-morbidity: 5-year assessment of patients with obesity and type 2 diabetes

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Background: **Bariatric surgery can be effective in weight reduction and diabetes remission in some patients, but is expensive. The costs of bariatric surgery in patients with obesity and type 2 diabetes mellitus (T2DM) were explored here.**

Methods: **Population-based retrospectively gathered data on patients with obesity and T2DM from the Hong Kong Hospital Authority (2006–2017) were evaluated. Direct medical costs from baseline up to 60 months were calculated based on the frequency of healthcare service utilization and dispensing of diabetes medication. Charlson Co-morbidity Index (CCI) scores and co-morbidity rates were measured to compare changes in co-morbidities between surgically treated and control groups over 5 years. One-to-five propensity score matching was applied.**

Results: **Overall, 401 eligible surgical patients were matched with 1894 non-surgical patients. Direct medical costs were much higher for surgical than non-surgical patients in the index year (€36 752 and €5788 respectively; $P < 0{\cdot}001$) mainly owing to the bariatric procedure. The 5-year cumulative costs incurred by surgical patients were also higher (€54 135 *versus* €28 603; $P < 0{\cdot}001$). ~~Patients~~ who had bariatric surgery had more visits to outpatient and allied health professionals than those who did not across the 5-year period. Surgical patients had significantly better CCI scores than controls after the baseline measurement (mean 3·82 *versus* 4·38 at 5 years; $P = 0{\cdot}016$). Costs of glucose-lowering medications were similar between two groups, except that surgical patients had significantly lower costs of glucose-lowering medications in year 2 (€973 *versus* €1395; $P = 0.012$).**

Conclusion: **Bariatric surgery in obese patients with T2DM is expensive, but leads to an improved co-morbidity profile, and reduced length of hospitalization.**

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Introduction

As populations age and lifestyles change, the prevalence of obesity and obesity-related type 2 diabetes mellitus (T2DM) is increasing worldwide[1]. Since 1980, the prevalence of obesity has doubled in over 70 countries[2], and the global number of patients with T2DM is projected to rise sharply from 451 million in 2017 to 693 million in 2045[3]. The alarming increase in the prevalence of diabetes is especially severe in Asian countries, the populations of which are more likely to develop T2DM at a lower BMI and a younger age than Caucasian populations[4]. The economic burden of both obesity-related disorders is exerting great pressure on healthcare systems[5,6].

Although lifestyle interventions are considered as the first-line treatment for patients with both obesity and T2DM[7], these are often limited by lack of patient commitment[8]. As a consequence, bariatric surgery has been suggested for the treatment of morbid obesity[9], and may improve T2DM and related complications in some patients[10–13]. The reported unit cost of bariatric procedures ranges from €6771 (US $7423) to €30 595 (US $33 541), with a mean of €13 125 (US $14 389)[14]. However, the mean cost of lifestyle intervention to achieve weight loss of 1 kg is only €49 (US $53·87) for 2 months (up to €916 (US $1005·36) for 12 months)[15]. It was expected that there would be reduced costs of prescriptions, outpatient visits and/or hospitalization in the early years of bariatrics[16–21]. However, most economic evaluations were conducted in the USA[17–19], and many healthcare systems differ from that in the USA in terms of costs and billing. This study aimed to estimate direct medical costs for patients with obesity and T2DM who had undergone bariatric surgery and those of matched non-surgical patients over a 5-year period.

Methods

The study design and population were described previously[22]. In brief, a population-based retrospective cohort of patients with obesity and T2DM who had ever used public healthcare services between January 2006 and December 2017 was assembled from the Clinical Management System managed by Hong Kong Hospital Authority (HA). Patients who had undergone bariatric surgery were identified based on a predefined list of ICD-9-CM procedure codes, whereas T2DM and other co-morbidities were identified through ICD-9-CM diagnosis codes and International Classification of Primary Care version 2 codes (*Table S1*, supporting information). Surgical patients were excluded if they underwent non-bariatric operations, did not have pre-existing T2DM, had no BMI readings or had a BMI reading below 27·5 kg/m^2 at the index date (date of bariatric surgery)[23]. A one-to-five propensity score matching method was used to match each eligible surgical patient with up to five non-surgical patients. The index date for non-surgical patients was the same as that of their matched surgical patients.

All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval for this study was granted by the Institutional Review Board of the University of Hong Kong /HA Hong Kong West Cluster (UW 16-1018). Consent was not obtained as the data were analysed anonymously.

Estimation of annual direct medical costs

The dates and frequency of the use of HA healthcare services by patients in the surgery and matched control group in the index year and subsequent 4 years were retrieved. Healthcare services included visits to general outpatient clinics, specialist outpatient clinics, accident and emergency departments and allied health professionals (clinical psychologists, dietitians, occupational therapists, physiotherapists, and smoking counselling and cessation visits), as well as duration of stay in a general ward, ICU, cardiac care unit and high-dependency unit. Unit costs of healthcare services were extracted from the public charges to non-eligible persons listed in the 2017 Government Gazette and HA Ordinance (Chapter 113)[24]. Additionally, for patients having bariatric surgery, the unit costs of bariatric and revisional procedures were estimated based on the private charges for operations (midpoint value) listed on the HA website[25] and personal communication with bariatric surgeons.

Data on types of antidiabetic drug prescribed and days' supply of each antidiabetic drug dispensed at each clinic visit during follow-up were also retrieved. Diabetes medications included were: insulin, metformin, thiazolidinedione, dipeptidyl peptidase 4 inhibitors, sodium glucose co-transporter 2 inhibitors and glucagon-like peptide 1 receptor agonists. Costs of diabetes medications per 30-day supply were based on published data[26], and the midpoints of the cost range for each class of diabetes medication were used to estimate the medication costs.

An exchange rate of €1·00 = HK $8·50 was used to convert Hong Kong dollars to euros. The unit costs of healthcare services and diabetes medications are summarized in *Table S2* (supporting information).

Annual direct medical costs for each patient were calculated based on the formula:

$$\begin{aligned}&\text{Annual direct medical costs}\\&= \Big(\sum \text{frequency of the healthcare service use}\\&\quad \text{in that year} \times \text{unit cost of the respective}\\&\quad \text{healthcare service}\Big) + \Big(\sum \text{days supply of diabetes}\\&\quad \text{medication} \times \text{midpoint of cost range of}\\&\quad \text{that medication} \div 30\Big).\end{aligned}$$

Changes in co-morbidities

Numbers of patients with various co-morbidities (hypertension, mental health problems, hyperlipidaemia, obstructive sleep apnoea, gallbladder disease, musculoskeletal and chronic orthopaedic disorders, cardiovascular disease (CVD), severe hypoglycaemia, chronic lung disease, chronic renal disease (CRD)) and in different Charlson Co-morbidity Index (CCI) categories (1, 2, 3, 4 or 5 and above, or died) were measured from baseline up to 60 months. Co-morbidity rates and CCI scores over the years were not adjusted for disease remission, owing to

Table 1 Characteristics of patients in bariatric surgery and matched control groups at baseline and 5 years

	Baseline				5 years		
	Bariatric surgery (n = 401)	Matched controls (n = 1894)	P‡	SMD†	Bariatric surgery (n = 117)	Matched controls (n = 582)	P‡
Sociodemographic data							
Age (years)*	53(13)	53(14)	0·916	0·006§	62(14)	61(14)	0·631§
Women	201 (50·1)	901 (47·6)	0·353	0·051	63 (53·8)	282 (48·5)	0·287
Clinical parameters*							
BMI (kg/m^2)	36·8(5·1)	36·3(6·1)	0·121§	0·090	32·2(5·5)	34·1(5·5)	0·032§
Waist circumference (cm)	113·2(12·0)	109·7(12·7)	< 0·001§	0·278	103·9(10·4)	109·5(12·4)	0·020§
HbA1c (%)	7·66(1·51)	7·56(1·77)	0·262§	0·065	6·92(1·44)	7·45(1·53)	0·009§
Systolic BP (mmHg)	134·7(16·8)	134·0(16·7)	0·520§	0·040	132·5(19·0)	132·6(16·3)	0·973§
Diastolic BP (mmHg)	77·5(10·4)	77·4(10·3)	0·809§	0·015	74·2(10·5)	75·7(9·6)	0·196§
Total cholesterol (mmol/l)	4·31(0·93)	4·27(0·92)	0·362§	0·050	4·43(0·74)	4·15(0·85)	0·008§
HDL-C (mmol/l)	1·09(0·29)	1·08(0·27)	0·536§	0·033	1·31(0·35)	1·13(0·29)	< 0·001§
TC/HDL-C ratio	4·20(1·31)	4·14(1·18)	0·364§	0·049	3·60(1·17)	3·88(1·13)	0·022§
LDL-C (mmol/l)	2·39(0·80)	2·35(0·75)	0·297§	0·057	2·42(0·62)	2·27(0·71)	0·109§
Triglyceride (mmol/l)	1·88(1·21)	1·90(1·33)	0·842§	0·011	1·58(1·11)	1·74(1·12)	0·216§
Fasting glucose (mmol/l)	8·01(2·86)	7·80(2·78)	0·181§	0·074	6·85(2·32)	7·79(3·09)	0·003§
Serum creatinine (μmol/l)	84·3(67·6)	84·0(54·6)	0·910§	0·006	93·8(114·6)	104·8(107·4)	0·379§
eGFR (ml per min per 1·73 m^2)	92·4(31·0)	90·8(30·1)	0·359§	0·050	83·4(28·3)	78·6(27·6)	0·003§
Co-morbidities							
Duration of DM (years)*	4·12(3·14)	4·36(2·84)	0·136§	0·079	7·46(2·09)	8·10(1·76)	< 0·001§
Insulin, ever used (%)	78 (19·5)	362 (19·1)	0·876	0·009	20 (17·1)	102 (17·5)	0·911
Oral antidiabetic drugs, ever used	231 (57·6)	1127 (59·5)	0·495	0·037	71 (60·7)	370 (63·6)	0·554
History of hypertension	319 (79·6)	1464 (77·3)	0·336	0·054	95 (81·2)	488 (83·8)	0·482
Antihypertensive drugs, ever used	313 (78·1)	1470 (77·6)	0·829	0·012	94 (80·3)	473 (81·3)	0·815
History of hyperlipidaemia	205 (51·1)	960 (50·7)	0·874	0·009	62 (53·0)	324 (55·7)	0·595
Lipid-lowering agents ever used	214 (53·4)	1059 (55·9)	0·351	0·051	64 (54·7)	329 (56·5)	0·716
History of mental health problems	21 (5·2)	112 (5·9)	0·598	0·029	13 (11·1)	53 (9·1)	0·499
History of obstructive sleep apnoea	220 (54·9)	1040 (54·9)	0·986	0·001	57 (48·7)	278 (47·8)	0·851
History of gallbladder disease	34 (8·5)	140 (7·4)	0·455	0·040	20 (17·1)	55 (9·5)	0·015
History of musculoskeletal and chronic orthopaedic disorders	98 (24·4)	481 (25·4)	0·689	0·022	31 (26·5)	154 (26·5)	0·398

Values in parentheses are percentages unless indicated otherwise; *values are mean(s.d.). †Standardized mean difference (SMD) below 0·100 indicates balance of baseline co-variable. Hb, haemoglobin; HDL-C, high-density lipoprotein cholesterol; TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; eGFR, estimated glomerular filtration rate; DM, diabetes mellitus. ‡χ^2 test, except §independent t test.

lack of data. Trends in mean CCI changes were analysed for both groups using tests for trends.

Statistical analysis

All statistical analyses were performed in Stata version 13.1 (StataCorp, College Station, Texas, USA). All significance tests were two-tailed and $P < 0{\cdot}050$ was considered statistically significant.

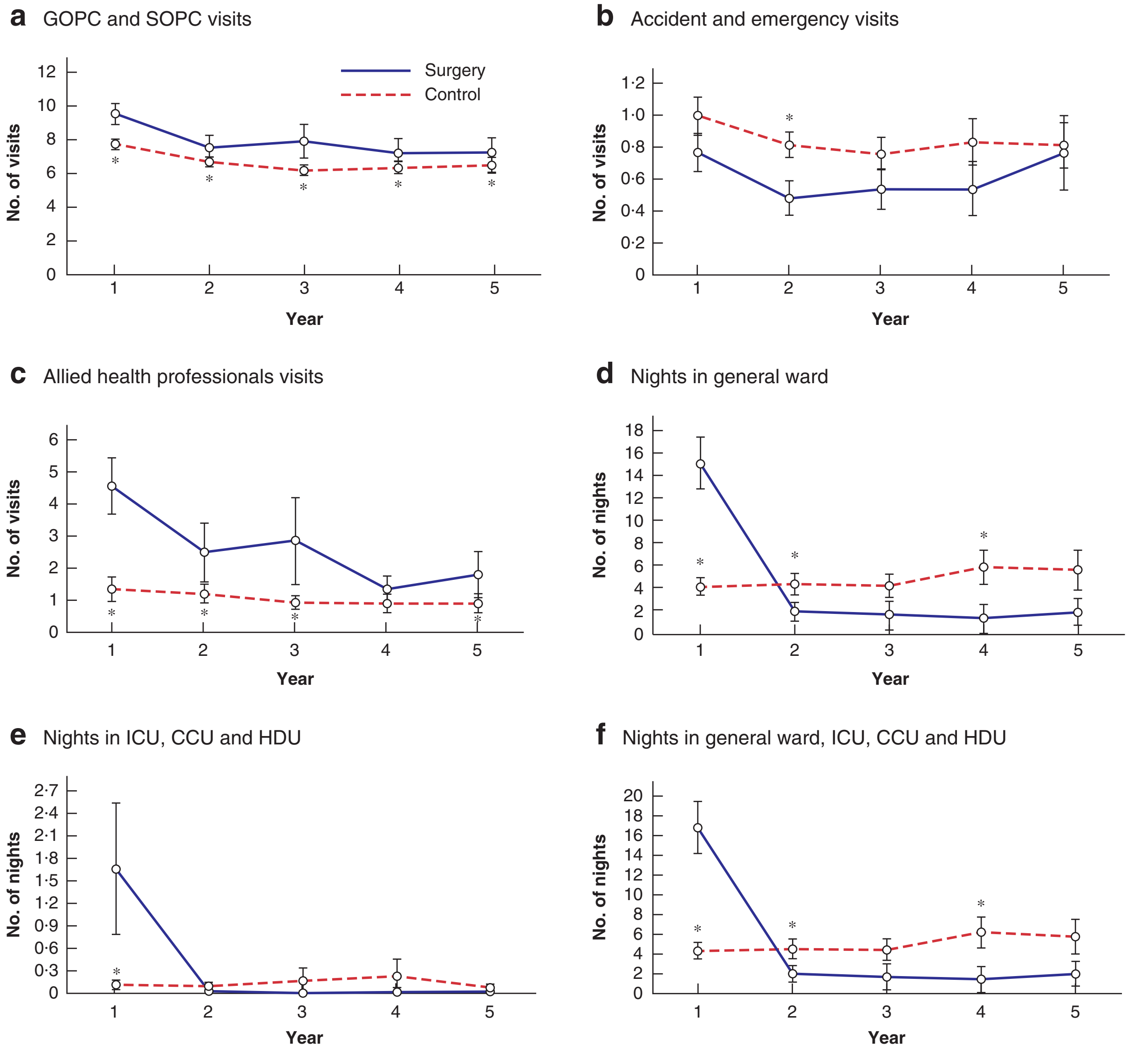
Baseline co-variables

Baseline co-variables included: age, sex, BMI, and pre-existing complications (hypertension, mental health problems, hyperlipidaemia, obstructive sleep apnoea, gallbladder disease, musculoskeletal and chronic orthopaedic disorders, CVD and CRD).

Propensity score matching method

Multiple imputation by chained equations[27] was used to address the absence of baseline data. Haemoglobin A_{1c} concentration, BP and low-density lipoprotein cholesterol level were imputed by sex, BMI, history of co-morbidities (hypertension, mental health problems, hyperlipidaemia, obstructive sleep apnoea, gallbladder disease, musculoskeletal and chronic orthopaedic disorders and CVD), duration of T2DM, CCI category, and use of insulin and oral antidiabetic drugs. Model parameters

Fig. 1 Frequency of health utilization for patients in bariatric surgery and control groups in the index year and subsequent 4 years



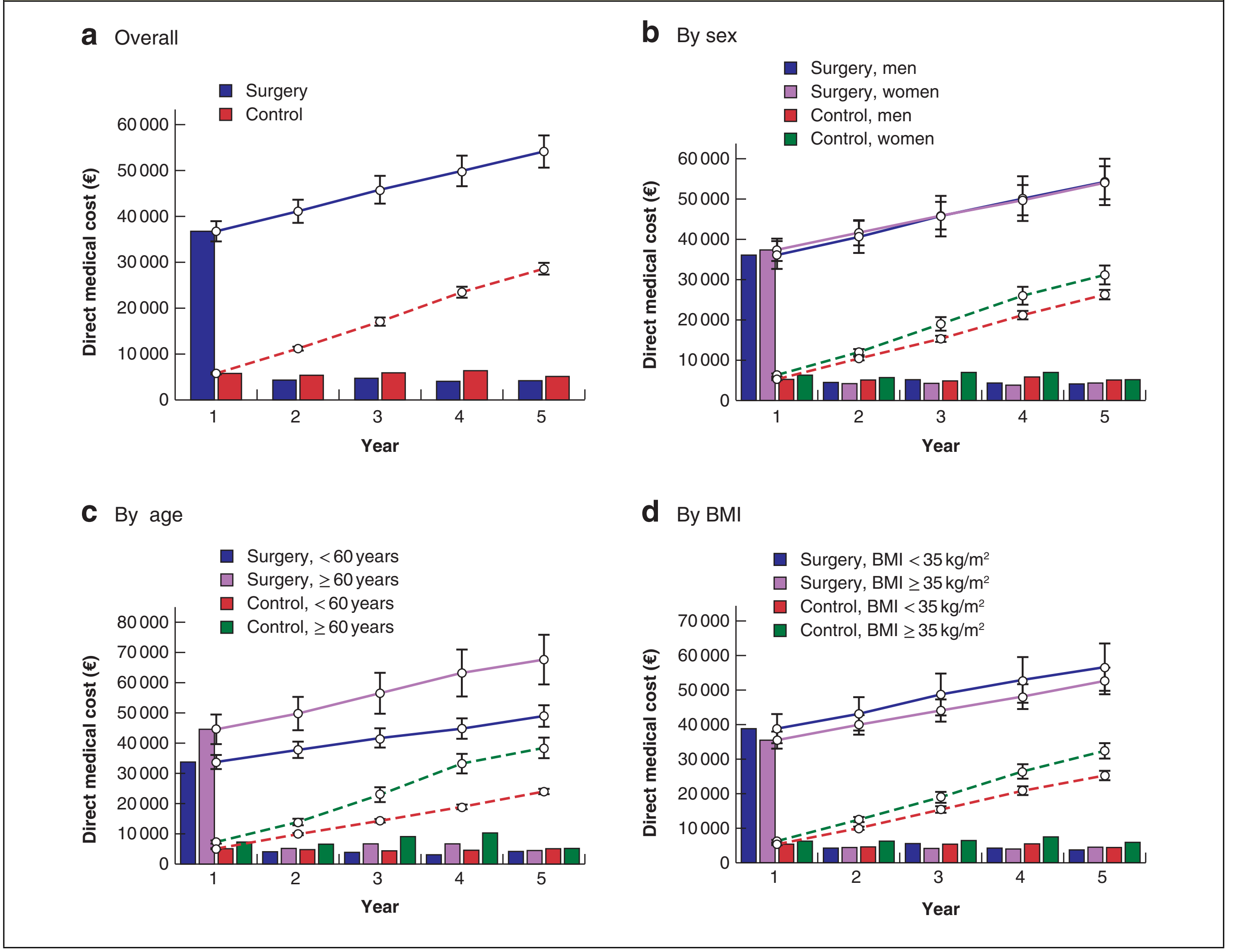
Visits to **a** general outpatient clinic (GOPC) and specialist outpatient clinic (SOPC), **b** accident and emergency department and **c** allied health professionals; nights in **d** general ward, **e** ICU, cardiac care unit (CCU) and high-dependency unit (HDU), and **f** general ward, ICU, CCU and HDU. Values are mean(s.d.). $P < 0{\cdot}050$ *versus* surgery group (t test).

were estimated from multiple imputed data and then used to obtain multiple-imputation linear predictions by applying Rubin's combination rules observation-wise to the completed-data predictions[28], whereby 20 imputed data sets were created for multiple imputations. Obtained predictions were then used in propensity score matching.

Each patient's propensity score was computed by multivariable logistic regression adjusting for their baseline co-variables. The calliper criteria improved the quality of the nearest-neighbour matching by specifying a maximum tolerance of the propensity score distance between patients in the surgical group and those in the control group. The propensity score matching was performed by means of the calipmatch command on a one-to-five basis without replacement in Stata®.

Baseline sociodemographic and clinical parameters, and co-morbidities of patients in both groups are presented as frequency with percentage for categorical variables and

Fig. 2 **Annual and cumulative direct medical costs in bariatric and control groups overall, and by sex, age and BMI**



a Overall, **b** by sex, **c** by age and **d** by BMI. Mean costs are shown for each year, along with mean(s.d.) cumulative costs.

mean(s.d.) for continuous variables. Independent *t* tests or χ^2 tests were used to assess differences in baseline characteristics between the two groups. The balance of baseline co-variables between groups after matching was measured by means of standardized mean differences (SMDs). All SMDs less than 0·100 implied optimal balance between the two groups[29].

Generalized linear models

Direct estimation of annual costs using a normal Gaussian distribution may be problematic owing to the skewness of the data and zero-cost issues[30]. Therefore, generalized linear models (GLMs) with gamma family and log-link were used to estimate the 5-year cumulative and annual direct medical costs accurately. GLMs, especially the gamma regression model, perform well in the estimation of non-negative and positively skewed cost data[31], and the model has been used widely in analyses of medical costs[32,33]. The GLM goodness of fit was tested by use of the modified Park test[34]. According to this test, a model coefficient approximating to 2 indicates that the use of the gamma distribution in GLMs is preferred.

The mean frequency and cost of visiting different types of healthcare service from the index year up to the fifth year in both groups of patients was determined. Estimated mean(s.d.) 5-year annual direct medical costs were calculated overall and for subgroups according to sex, age (less than 60 years *versus* 60 years and over), BMI (less than 35 kg/m^2 *versus* 35 kg/m^2 or higher), duration of T2DM (5 years or less *versus* over 5 years), CCI category

Table 2 Differences between groups in annual direct medical costs and cumulative costs overall, and in subgroups of age, sex and BMI

	Mean annual direct medical costs (€)					
	Year 1	Year 2	Year 3	Year 4	Year 5	Mean cumulative costs (€)
Overall						
Surgery (*n* = 401)	36 752	4362	4697	4096	4228	54 135
Control (*n* = 1894)	5788	5397	5891	6402	5124	28 603
Incremental costs	30 964	−1035	−1194	−2307	−896	25 532
*P**	< 0·001	< 0·001	0·039	< 0·001	< 0·001	< 0·001
Sex						
Men						
Surgery (*n* = 200)	36 105	4496	5151	4345	4142	54 240
Control (*n* = 993)	5285	5136	4895	5875	5091	26 283
Incremental costs	30 820	−640	256	−1530	−949	27 957
*P**	< 0·001	0·030	0·603	< 0·001	< 0·001	< 0·001
Women						
Surgery (*n* = 201)	37 396	4229	4245	3847	4313	54 030
Control (*n* = 901)	6342	5685	6989	6983	5160	31 159
Incremental costs	31 054	−1457	−2744	−3136	−847	22 871
*P**	< 0·001	0·001	0·010	< 0·001	0·001	< 0·001
Age						
< 60 years						
Surgery (*n* = 290)	33 760	4035	3925	3100	4149	48 970
Control (*n* = 1290)	5086	4822	4414	4592	5088	24 003
Incremental costs	28 675	−786	−490	−1492	−939	24 967
*P**	< 0·001	0·001	0·138	< 0·001	< 0·001	< 0·001
≥ 60 years						
Surgery (*n* = 111)	44 568	5215	6714	6698	4434	67 629
Control (*n* = 604)	7287	6626	9045	10 268	5201	38 427
Incremental costs	37 281	−1411	−2331	−3570	−767	29 202
*P**	< 0·001	0·037	0·182	0·001	0·031	< 0·001
BMI						
< 35 kg/m^2						
Surgery (*n* = 150)	38 829	4279	5607	4219	3700	56 635
Control (*n* = 1008)	5363	4643	5422	5445	4394	25 266
Incremental costs	33 466	−364	185	−1226	−694	31 368
*P**	< 0·001	0·264	0·807	0·008	0·005	< 0·001
≥ 35 kg/m^2						
Surgery (*n* = 251)	35 511	4411	4153	4022	4544	52 641
Control (*n* = 886)	6271	6255	6425	7491	5955	32 398
Incremental costs	29 239	−1844	−2272	−3469	−1411	20 243
*P**	< 0·001	< 0·001	0·009	< 0·001	< 0·001	< 0·001

**t* test.

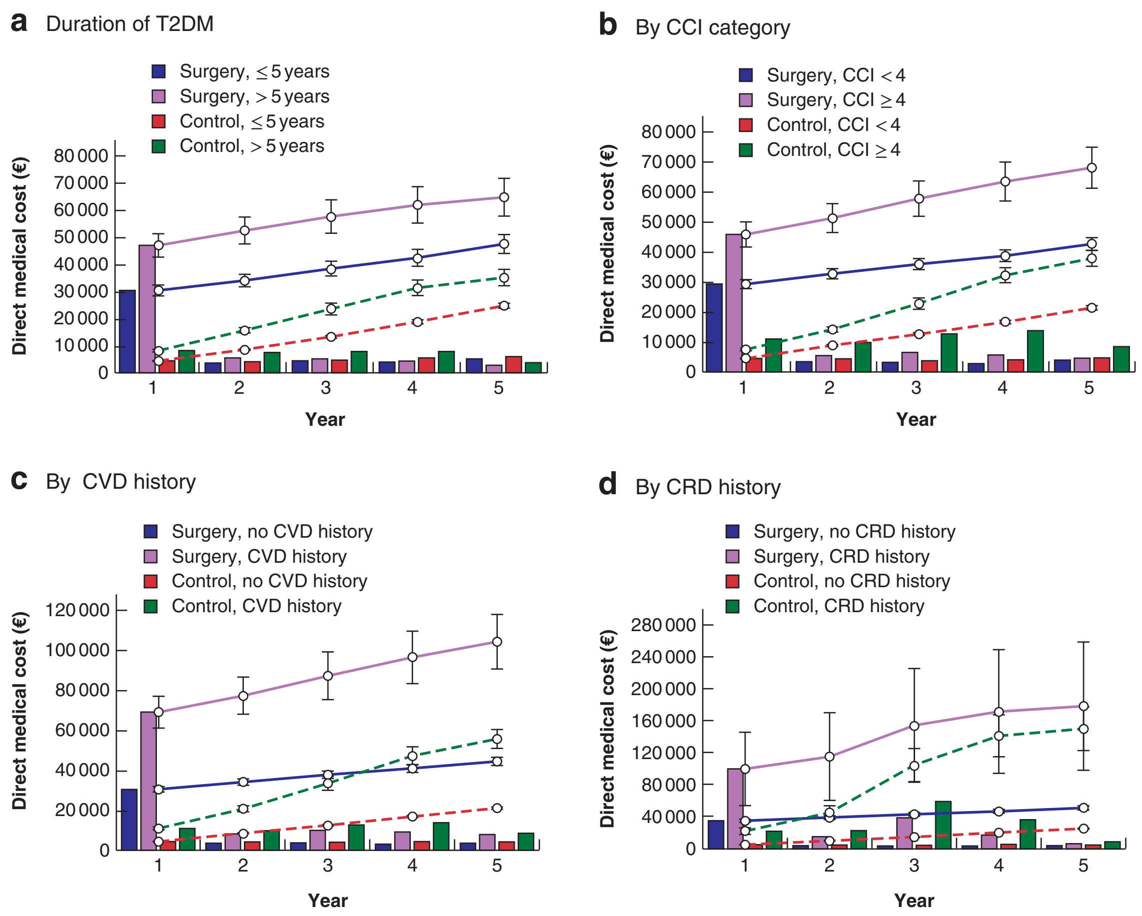
(less than 4 *versus* 4 or more), and history of CVD and CRD.

Results

A total of 422 patients with obesity and diabetes met the criteria for inclusion in the surgery group. After propensity score matching, a cohort of 2295 patients (401 surgical patients and 1894 matched controls) were included in the present analysis (*Fig. S1*, supporting information).

The baseline characteristics of the two groups were well balanced (*Table 1*; *Fig. S2*, supporting information). The mean BMI of surgery and control patients was 36·8 and 36·3 kg/m^2 respectively ($P = 0{\cdot}121$, SMD 0·090). The mean age of both groups was 53 years. Of 401 surgical patients, 299 (74·6 per cent) underwent laparoscopic sleeve

Fig. 3 **Annual and cumulative direct medical costs in bariatric and control groups according to co-morbidities**



a By duration of type 2 diabetes mellitus (T2DM), **b** by Charlson Co-Morbidity Index (CCI) category, **c** by history of cardiovascular disease (CVD) and **d** by history of chronic renal disease (CRD). Values are mean(s.d.). Mean costs are shown for each year, along with mean(s.d.) cumulative costs.

gastrectomy, 74 (18·5 per cent) laparoscopic gastric bypass, 11 (2·7 per cent) laparoscopic adjustable gastric banding and 17 (4·2 per cent) had laparoscopic sleeve gastrectomy with duodenojejunal bypass.

Frequency and costs of use of healthcare services

The mean number of outpatient visits each year in both groups was between six and ten. Surgical patients had more visits to outpatient clinics and allied health professionals than non-surgical patients across the 5 years (*Fig. 1*). The mean number of emergency visits per year in both groups was less than one, and the difference was significant only in year 2 (0·48 and 0·84 in surgery and control groups respectively; $P < 0.001$). Patients in the bariatric surgery group had a longer mean length of stay in hospital wards than non-surgical patients in the index year (16·8 *versus* 4·4 nights; $P < 0.001$). However, surgical patients had a shorter hospital stay than non-surgical patients in subsequent years. For both groups, the largest component of annual direct medical costs was inpatient services in the first year, followed by outpatient services, allied health professional visits and emergency visits (*Fig. S3*, supporting information). Reoperation rates for surgical patients over time are given in in *Table S5* (supporting information).

Dispensing days and costs of glucose-lowering medications

Costs of glucose-lowering medications were similar between two groups, except that surgical patients had

Table 3 Differences between groups in annual direct medical costs and cumulative costs in subgroups according to co-morbidities

	Mean annual direct medical costs (€)					
	Year 1	Year 2	Year 3	Year 4	Year 5	Mean cumulative costs (€)
Duration of T2DM						
≤ 5 years						
Surgery (*n* = 247)	30 375	3649	4412	3977	5099	47 512
Control (*n* = 1190)	4385	4137	4737	5557	5925	24 742
Incremental costs	25 990	−488	−325	−1580	−827	22 770
*P**	< 0·001	0·005	0·321	< 0·001	0·001	< 0·001
> 5 years						
Surgery (*n* = 154)	46 980	5505	5154	4286	2832	64 757
Control (*n* = 704)	8159	7526	7841	7831	3770	35 128
Incremental costs	38 821	−2021	−2688	−3545	−938	29 629
*P**	< 0·001	0·001	0·059	< 0·001	< 0·001	< 0·001
CCI category						
< 4						
Surgery (*n* = 220)	29 278	3460	3226	2780	3914	42 658
Control (*n* = 1064)	4477	4393	3755	4014	4739	21 378
Incremental costs	24 801	−932	−529	−1235	−826	21 280
*P**	< 0·001	< 0·001	0·017	< 0·001	< 0·001	< 0·001
≥ 4						
Surgery (*n* = 181)	45 837	5458	6484	5695	4610	68 084
Control (*n* = 830)	7469	6685	8629	9464	5617	37 864
Incremental costs	38 368	−1227	−2145	−3768	−1008	30 221
*P**	< 0·001	0·016	0·084	< 0·001	< 0·001	< 0·001
History of CVD						
Yes						
Surgery (*n* = 65)	69 059	8270	9938	9184	7828	104 279
Control (*n* = 412)	10 947	9802	12 741	13 722	8457	55 669
Incremental costs	58 112	−1531	−2804	−4538	−629	48 610
*P**	< 0·001	0·145	0·311	0·003	0·283	< 0·001
No						
Surgery (*n* = 336)	30 502	3606	3683	3111	3531	44 434
Control (*n* = 1482)	4354	4173	3987	4367	4198	21 078
Incremental costs	26 149	−567	−304	−1256	−666	23 356
*P**	< 0·001	< 0·001	0·154	< 0·001	< 0·001	< 0·001
History of CRD						
Yes						
Surgery (*n* = 9)	100 062	15 446	38 987	17 346	6678	178 521
Control (*n* = 48)	22 291	23 111	59 471	36 578	8827	150 278
Incremental costs	77 771	−7665	−20 484	−19 232	−2148	28 242
*P**	< 0·001	0·173	0·164	0·016	0·227	0·924
No						
Surgery (*n* = 392)	35 299	4107	3910	3792	4172	51 279
Control (*n* = 1846)	5359	4937	4498	5618	5028	25 439
Incremental costs	29 940	−829	−588	−1826	−856	25 840
*P**	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001

T2DM, type 2 diabetes mellitus; CCI, Charlson Co-Morbidity Index; CVD, cardiovascular disease; CRD, chronic renal disease. **t* test.

Table 4 Patients with co-morbidities at baseline and during follow-up

	Baseline	Year 1	Year 2	Year 3	Year 4	Year 5	Absolute % increase over 5 years
Surgery (*n* = 401)							
Hypertension	319 (79·6)	327 (81·5)	328 (81·8)	329 (82·0)	329 (82·0)	330 (82·3)	2·7
Mental health problems	21 (5·2)	27 (6·7)	29 (7·2)	30 (7·5)	30 (7·5)	32 (8·0)	2·7
Hyperlipidaemia	205 (51·1)	219 (54·6)	220 (54·9)	223 (55·6)	226 (56·4)	227 (56·6)	5·5
Obstructive sleep apnoea	220 (54·9)	227 (56·6)	230 (57·4)	230 (57·4)	232 (57·9)	233 (58·1)	3·2
Gallbladder disease	34 (8·5)	39 (9·7)	41 (10·2)	41 (10·2)	42 (10·5)	44 (11·0)	2·5
Musculoskeletal and chronic orthopaedic disorders	98 (24·4)	104 (25·9)	109 (27·2)	110 (27·4)	111 (27·7)	113 (28·2)	3·7
Cardiovascular disease							
Acute myocardial infarction	8 (2·0)	9 (2·2)	9 (2·2)	10 (2·5)	11 (2·7)	11 (2·7)	0·7
Other ischaemic heart disease	29 (7·2)	30 (7·5)	31 (7·7)	32 (8·0)	33 (8·2)	33 (8·2)	1·0
Congestive heart failure	15 (3·7)	17 (4·2)	17 (4·2)	17 (4·2)	17 (4·2)	17 (4·2)	0·5
Stroke	17 (4·2)	18 (4·5)	18 (4·5)	20 (5·0)	21 (5·2)	23 (5·7)	1·5
Peripheral vascular disease	10 (2·5)	11 (2·7)	11 (2·7)	11 (2·7)	11 (2·7)	11 (2·7)	0·2
Severe hypoglycaemia	64 (16·0)	71 (17·7)	72 (18·0)	73 (18·2)	74 (18·5)	75 (18·7)	2·7
Chronic lung disease	12 (3·0)	13 (3·2)	14 (3·5)	14 (3·5)	14 (3·5)	15 (3·7)	0·7
Chronic renal disease	5 (1·2)	6 (1·5)	6 (1·5)	6 (1·5)	7 (1·7)	7 (1·7)	0·5
Control (*n* = 1894)							
Hypertension	1464 (77·3)	1489 (78·6)	1520 (80·3)	1532 (80·9)	1545 (81·6)	1549 (81·8)	4·5
Mental health problems	112 (5·9)	125 (6·6)	131 (6·9)	137 (7·2)	139 (7·3)	144 (7·6)	1·7
Hyperlipidaemia	960 (50·7)	1014 (53·5)	1063 (56·1)	1094 (57·8)	1113 (58·8)	1120 (59·1)	8·4
Obstructive sleep apnoea	1041 (55·0)	1054 (55·6)	1063 (56·1)	1068 (56·4)	1077 (56·9)	1079 (57·0)	2·0
Gallbladder disease	140 (7·4)	145 (7·7)	151 (8·0)	153 (8·1)	155 (8·2)	156 (8·2)	0·8
Musculoskeletal and chronic orthopaedic disorders	483 (25·5)	519 (27·4)	549 (29·0)	585 (30·9)	601 (31·7)	620 (32·7)	7·2
Cardiovascular disease							
Acute myocardial infarction	42 (2·2)	49 (2·6)	51 (2·7)	60 (3·2)	63 (3·3)	69 (3·6)	1·4
Other ischaemic heart disease	196 (10·3)	208 (11·0)	227 (12·0)	237 (12·5)	242 (12·8)	248 (13·1)	2·7
Congestive heart failure	150 (7·9)	165 (8·7)	180 (9·5)	197 (10·4)	203 (10·7)	207 (10·9)	3·0
Stroke	142 (7·5)	159 (8·4)	179 (9·5)	188 (9·9)	195 (10·3)	199 (10·5)	3·0
Peripheral vascular disease	50 (2·6)	56 (3·0)	60 (3·2)	65 (3·4)	69 (3·6)	69 (3·6)	1·0
Severe hypoglycaemia	260 (13·7)	287 (15·2)	310 (16·4)	320 (16·9)	328 (17·3)	334 (17·6)	3·9
Chronic lung disease	87 (4·6)	91 (4·8)	100 (5·3)	105 (5·5)	109 (5·8)	112 (5·9)	1·3
Chronic renal disease	56 (3·0)	70 (3·7)	80 (4·2)	94 (5·0)	102 (5·4)	106 (5·6)	2·6

Values in parentheses are percentages. Patients were assumed to have the chronic diseases listed throughout follow-up once they had been diagnosed. Co-morbidity rates were not adjusted for disease remission and loss to follow-up.

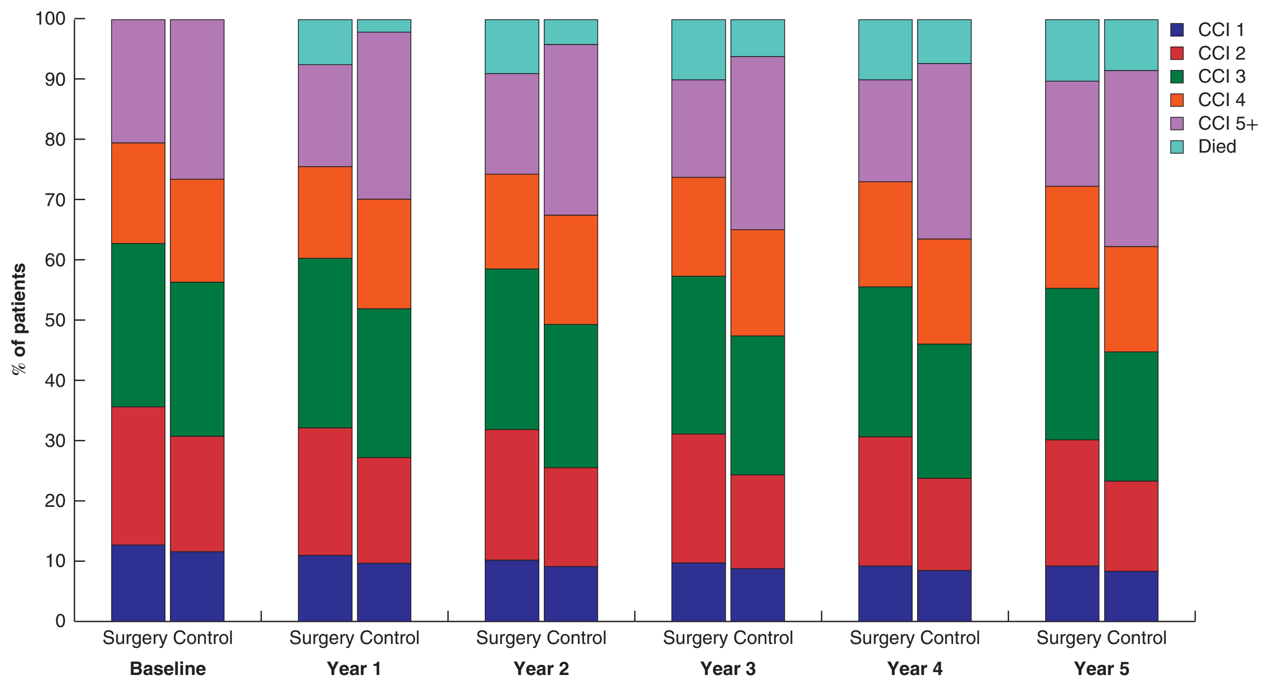
significantly lower costs of glucose-lowering medications in year 2 (€973 versus €1395; $P = 0.012$). Annual total medication costs were stable for control patients, fluctuating between €1323 and €1553 (*Table S3*, supporting information). Medication costs for surgical patients dipped, but were not eliminated in the first 2 years after surgery (€1752 in year 1 and €973 in year 2) and then increased to €1836 in year 5. Indeed, the costs of glucose-lowering medication were actually higher for surgical than non-surgical patients in years 1 and 5 (not significantly different), although the amount of insulin prescribed decreased after operation.

Estimated annual and cumulative direct medical costs

The coefficients of the GLMs constructed for predicting medical costs in each year were 1·43, 1·90, 1·94, 2·11 and 1·88, indicating that the use of GLMs with gamma family and log-link in the data set were generally supported. The impact of baseline covariates on annual medical costs are listed in *Table S6* (supporting information).

~~Surgical patients incurred greater medical costs than control patients in the year before the index year (€6832 versus €5228, $P = 0{\cdot}046$) (*Table S7*, supporting information).~~ Surgical patients incurred greater medical costs than control patients in the year before the index year

Fig. 4 **Distribution of patients in bariatric surgery and control groups according to Charlson Co-morbidity Index category**



CCI, Charlson Co-morbidity Index.

(€6832 versus €5228, $P = 0{\cdot}046$) (*Table S7*, supporting information). Annual and cumulative direct medical costs overall and in various subgroups are summarized in *Figs 2* and *3*, and differences between the treatment groups are shown in *Tables 2* and *3*. Overall, the mean(s.d.) direct medical cost for the bariatric surgery group in the year of surgery was €36 752(22 448), nearly seven times that in the matched control group (€5788(4692)) ($P < 0{\cdot}001$). In subsequent years, medical costs ranged from €4096(3770) to €4697(6468) in surgical patients compared with €5124(3324) to €6402(7181) in non-surgical patients. In the 4-year postoperative follow-up, annual costs for surgical patients were significantly lower than those for their non-surgical counterparts (all $P < 0{\cdot}050$). Over the 5-year follow-up, cumulative costs of €54 135(35 746) and €28 603(28 363) were incurred by surgical and non-surgical patients respectively ($P < 0{\cdot}001$).

Similarly, surgical patients had significantly higher cumulative medical costs in all subgroups, except for those with pre-existing CRD. Patients in poorer health (such as older patients, those with longer duration of T2DM, more co-morbidities, and presence of CVD and CRD) incurred greater medical costs than their counterparts who were in better health. Of note, cumulative medical costs of surgical patients with a history of CRD exceeded €170 000 over the 5 years, ranking the highest among all subgroups.

Changes in co-morbidity profiles

Table 4 shows rates of various co-morbidities over the years. Over the 60 months, a smaller percentage of surgical patients newly developed hypertension, hyperlipidaemia, musculoskeletal and chronic orthopaedic disorders, CVD, severe hypoglycaemia, chronic lung disease and CRD. Mean CCI score in both groups from baseline to 60 months is shown in *Fig. S4* (supporting information). Mean CCI score was similar in the two groups, but surgical patients had significantly lower scores than controls in subsequent years (3·82 *versus* 4·38 respectively in year 5; $P = 0{\cdot}016$). Although the mean value in the surgery group increased from 3·40 to 3·82, the P for trend was 0·443, indicating that the CCI score was stable among surgical patients. In contrast, P for trend in the control patients was less than 0·001.

The percentage of patients in low CCI categories decreased, as patients proceeded towards high CCI categories or died in each year (*Fig. 4*). More surgical patients died at 12 months, but thereafter patients in this group seemed to proceed more slowly to CCI category at least 5 or death than non-surgical patients. Over half of deaths among surgical patients in the first 12 months after surgery were due to cancer and none to bariatric surgery. Causes of death for both groups over the years are summarized in *Table S4* (supporting information).

Discussion

The findings of this study have provided additional information on the medical costs of bariatric surgery in an Asian context in patients with obesity and T2DM. Surgical patients had significantly higher medical costs overall. The inpatient costs for surgical patients were significant in the year of surgery, but were a little lower than those of control patients in subsequent years. Other studies[18,19,35,36] reported higher inpatient costs after bariatric surgery, with annual costs broadly similar thereafter.

Previous studies[17,20,36–38] suggested that the amount of diabetes medication per patient dropped after bariatric surgery. The present results, however, showed a U-shape curve for the costs of diabetes drugs in patients who had undergone bariatric surgery, with disappointingly persistent or recurrent diabetes. Cumulative costs for surgical and non-surgical patients are expected to converge 22 years after surgery if other conditions remain unchanged. This is consistent with the finding of a systematic review[39] that bariatric surgery raised the total medical costs in the short to medium term but might be cost-saving in the long term.

Of note, the relative differences (ratio between 5-year cumulative costs of surgery and control patients) in 5-year cumulative costs between surgical and non-surgical patients were smaller in subgroups of patients who had a BMI of 35 kg/m^2 or more, a CCI score of 4 or higher, or history of CVD or CRD. These results implied that there may be a shorter time to break even in these subgroups, and so bariatric surgery was suggested more for patients with obesity and T2DM with such features. Notably, among patients with CRD, patients in the surgery group had similar 5-year cumulative medical costs to those in the control group. One possible explanation is that bariatric surgery has renal protective effects, even in patients with established renal diseases[40–44]. Improved renal function after bariatric surgery largely reduced the annual medical costs of surgical patients in the postoperative years.

Some limitations should be acknowledged, including that one-to five matching is less common than one-to-one propensity score matching. It increases precision in cohort studies at only a small cost of bias[45]. Patients treated between 2006 and 2017 were included, but those whose index year was 2014 or later have not yet completed 5-year follow-up so costs for these patients were extrapolated. In particular, bariatric surgery had protective effects against hypertension, hyperlipidaemia, musculoskeletal and chronic orthopaedic disorders, CVD, severe hypoglycaemia, chronic lung disease and CRD.

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Supporting information

Additional supporting information can be found online in the Supporting Information section at the end of the article.

Graphical Abstract

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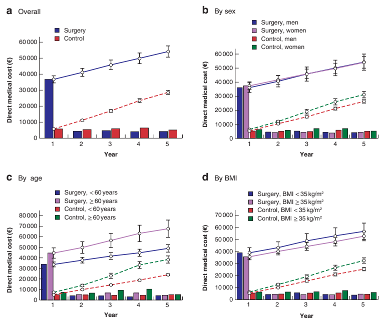

Direct medical costs and changes in co-morbidities up to 5 years after bariatric surgery were measured among patients with obesity and type 2 diabetes mellitus. Although surgical patients incurred significantly greater medical costs in the index year and 5-year cumulative costs than non-surgical patients, they had an improved co-morbidity profile.